Author(s): Pirjo Peltonen-Sainio, Lauri Jauhiainen, Juuso Joona, Tuomas J. Mattila, Tony Hydén & Hannu Känkänen

Title: Farm characteristics shape farmers' cover crop choices in Finland

Year: 2024

Version: Published version

Please cite the original version:

Pirjo Peltonen-Sainio, Lauri Jauhiainen, Juuso Joona, Tuomas J. Mattila, Tony Hydén & Hannu Känkänen (2024) Farm characteristics shape farmers' cover crop choices in Finland, International Journal of Agricultural Sustainability, 22:1, 2299596, DOI: 10.1080/14735903.2023.2299596

Taylor & Francis
Taylor & Francis Group

International Journal of Agricultural Sustainability

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tags20

Farm characteristics shape farmers' cover crop choices in Finland

Pirjo Peltonen-Sainio, Lauri Jauhiainen, Juuso Joona, Tuomas J. Mattila, Tony Hydén & Hannu Känkänen

To cite this article: Pirjo Peltonen-Sainio, Lauri Jauhiainen, Juuso Joona, Tuomas J. Mattila, Tony Hydén & Hannu Känkänen (2024) Farm characteristics shape farmers' cover crop choices in Finland, International Journal of Agricultural Sustainability, 22:1, 2299596, DOI: 10.1080/14735903.2023.2299596

To link to this article: https://doi.org/10.1080/14735903.2023.2299596

INTERNATIONAL JOURNAL OF AGRICULTURAL SUSTAINABILITY
2024, VOL. 22, NO. 1, 2299596
https://doi.org/10.1080/14735903.2023.2299596

Farm characteristics shape farmers' cover crop choices in Finland

Pirjo Peltonen-Sainio [a], Lauri Jauhiainen[b], Juuso Joona[c], Tuomas J. Mattila[d], Tony Hydén[e] and Hannu Känkänen[b]

[a]Natural Resources Institute Finland (Luke), Helsinki, Finland; [b]Natural Resources Institute Finland (Luke), Jokioinen, Finland; [c]Tyynelä Farm, Imatra, Finland; [d]Finnish Environment Institute (SYKE), Helsinki, Finland; [e]Koivumäki Farm, Loviisa, Finland

ABSTRACT

Cover crops (CCs) are a diverse group of species that are sown simultaneously or after the cash crop either as monocrops or mixtures. A farmer survey with 1130 respondents was carried out with the aim to gain knowledge on CC species used by Finnish farmers, to understand how experienced farmers were with them, how experiences varied depending on farm and farmer characteristics, and to identify target groups for dissemination and policy measures. The studied groups were conventional and organic farms that had selected CCs as a registered measure in 2020 to receive agricultural payments. Our results show that farmers were experienced with a high number of CCs despite the high-latitude conditions. Only 11% of respondents had plenty of experience with CCs as mixtures. Farmers tended to favour CCs that were familiar to them as cash crops. Organic producers were usually more experienced than conventional farmers. Education increased curiosity towards CCs. Farmers who used more diverse cash crops tended to use more diverse CCs. In conclusion, especially farmers who have cereal-based systems and rotations should be a core group for knowledge sharing to support transition towards increased use of CCs and higher diversity of CC species in the future.

ARTICLE HISTORY
Received 4 April 2022
Accepted 22 December 2023

KEYWORDS
Cover crop; catch crop; diversification; education; farm; land use; organic production; mixture

1. Introduction

Cover crops (CCs) have piqued researchers and farmers interest as they can provide various benefits for agricultural systems while simultaneously reducing the environmental footprint (Blanco-Canqui et al., 2015; Daryanto et al., 2018; Lamichhane & Alletto, 2022). These include potential ecosystem services for restoring soil structure, conditions and functionality (Adetunji et al., 2020; Kim et al., 2020; Koudahe et al., 2022; Ruis & Blanco-Canqui, 2017; Scavo et al., 2022), improving nutrient dynamics, cycling and scavenging (De Notaris et al., 2020; Nouri et al., 2022) and suppressing weeds (Lemessa & Wakjira, 2015; Osipitan et al., 2018; Rouge et al., 2022). Success in the cultivation of CCs and the benefits provided for agricultural systems and the environment are, however, very site specific (i.e. weather-, soil-, management-specific), which calls for a more comprehensive understanding of how regional features shape the potential multiple benefits provided by CCs (Blanco-Canqui et al., 2015).

Cover crops are a diverse group of species. There is lack of systematic data about the CC species grown by farmers in different regions, which highlights the novelty of this study. Often over-wintering green biomass is targeted with cultivation of CCs when aiming to mitigate nutrient loss (Aronsson et al., 2016; Valkama et al., 2015; Vogeler et al., 2019) and protect soil against high post-harvest precipitation typical for Finland (Peltonen-Sainio et al., 2016), where this study took place. Climate change may increase these risks in the future (Ruosteenoja et al.,

CONTACT Pirjo Peltonen-Sainio pirjo.peltonen-sainio@luke.fi Natural Resources Institute Finland (Luke), Latokartanonkaari 9, FI-00790 Helsinki, Finland
Supplemental data for this article can be accessed online at https://doi.org/10.1080/14735903.2023.2299596.

2016). The list of species that can be used as CCs is virtually endless though to a certain extent they are region specific. Cover crops are not primarily grown to produce a harvestable yield, which explains high number of alternative CCs compared to cash crops. Farmers may, however, pursue different effects with CCs, which again is dependent on the farm characteristics, cropping systems and management (Blanco-Canqui et al., 2015; Sieling, 2019). In addition to the functional (growth performance, nutrient dynamics, competition) and management linked traits of CCs (crop protection, termination, crop residues) that support the coexistence with primary crops, farmers weigh the role of CCs in relation to their cost-effectiveness and potential to provide services for the plant–soil system and environment (Daryanto et al., 2018). Potential emerging risks that CCs may bring should also be proactively considered and avoided. For example, CCs may serve as a green-bridge for pests and diseases within the cropping system (Hart, 2020), and volunteer plants may present problems for subsequent crops (Stoa, 1933).

Success in introducing CCs into a farming system and benefitting from their various potential ecosystems services is very context dependent, because many site-specific factors impact availability and functionality of CCs in prevailing conditions and farming systems (Costantini et al., 2020; Daryanto et al., 2018; Vincent-Caboud et al., 2017). In this study, we used a farmer survey to have an overview of the current use of CCs species in Finland and to understand how CCs species selection varied depending on the farmer and farm characteristics such as the farmer's age, education, region, the farming system in use, the farm type, farm size and area under cereal cultivation, and whether there are grasslands, special crops and other diversifying crops on the farm. This is an opportune moment for such a survey as area under CCs has started to increase dramatically in Finland (Aronsson et al., 2016) from 23,000 ha in 2010 to 138,000 ha in 2020 (Peltonen-Sainio et al., 2023) – also on conventional farms, while traditionally their use has mostly been favoured by organic producers with the aim to fix nitrogen with legumes and compete against weeds. Such novel data on CC choices and their use depending on the farm and farmer characteristics serves as essential, so far hidden knowledge, to support a deeper understanding of the farmers' successes and failures with CCs. This is especially important considering future financial and practical support needed by farmers when introducing and further expanding the cultivation of CCs.

2. Materials and methods

2.1. Implementation of the farmer survey and utilized background data

The farmer survey was carried out in Finland in spring 2021. In total, the details of 7025 farms (16% of Finnish farms in 2021) were requested and received from the registry of the Finnish Food Authority (FFA). These included the farm identification number, farm type, location, parcel identification number with CCs and the farmer's email-address. The farmers whose data was sought from the FFA were organic and conventional farms that applied for agricultural payments for CCs in 2020. Agricultural payments were registered at field parcel scale. With these definitions, the FFA provided requested data on 5593 conventional farms and 1432 organic farms. As farmers were contacted by email, only those whose email-addresses were available in the registry of the FAA were used as respondents. With these definitions the total number of invited farmers was 6493.

The survey started on 16th March 2021 and ended on 11th April 2021. One reminder message was sent on 30th March 2021. The primary questions analysed in this study were '*Which CCs do you have first-hand experience with?*' and '*Do you have experience in growing CCs as mixtures?*'. The survey included also other questions with altogether 51 statements, all dealing with CCs (see, e.g. Peltonen-Sainio, Jauhiainen, Känkänen et al., 2022, Peltonen-Sainio, Jauhiainen, Mattila et al., 2022, 2023). Farmers were informed that by CCs we meant those used as under-sown crops, catch crops, break-CCs and winter-time crop cover, i.e. CCs which were sown either under or after the primary crop. In total 28 CCs species were listed for farmers so that they could tick off one of the following five answer choices for each CC as a response to the question how much they had first-hand experience with each species: 1 = none, 2 = very little, 3 = somewhat, 4 = a lot and 5 = very much. There was space to write the name of some additional species farmers had experience with, but this did not provide sufficient data to be included in the analyses. The list of species involved in this study is shown in Figure 1. The same five answer choices as for specific CCs species were also

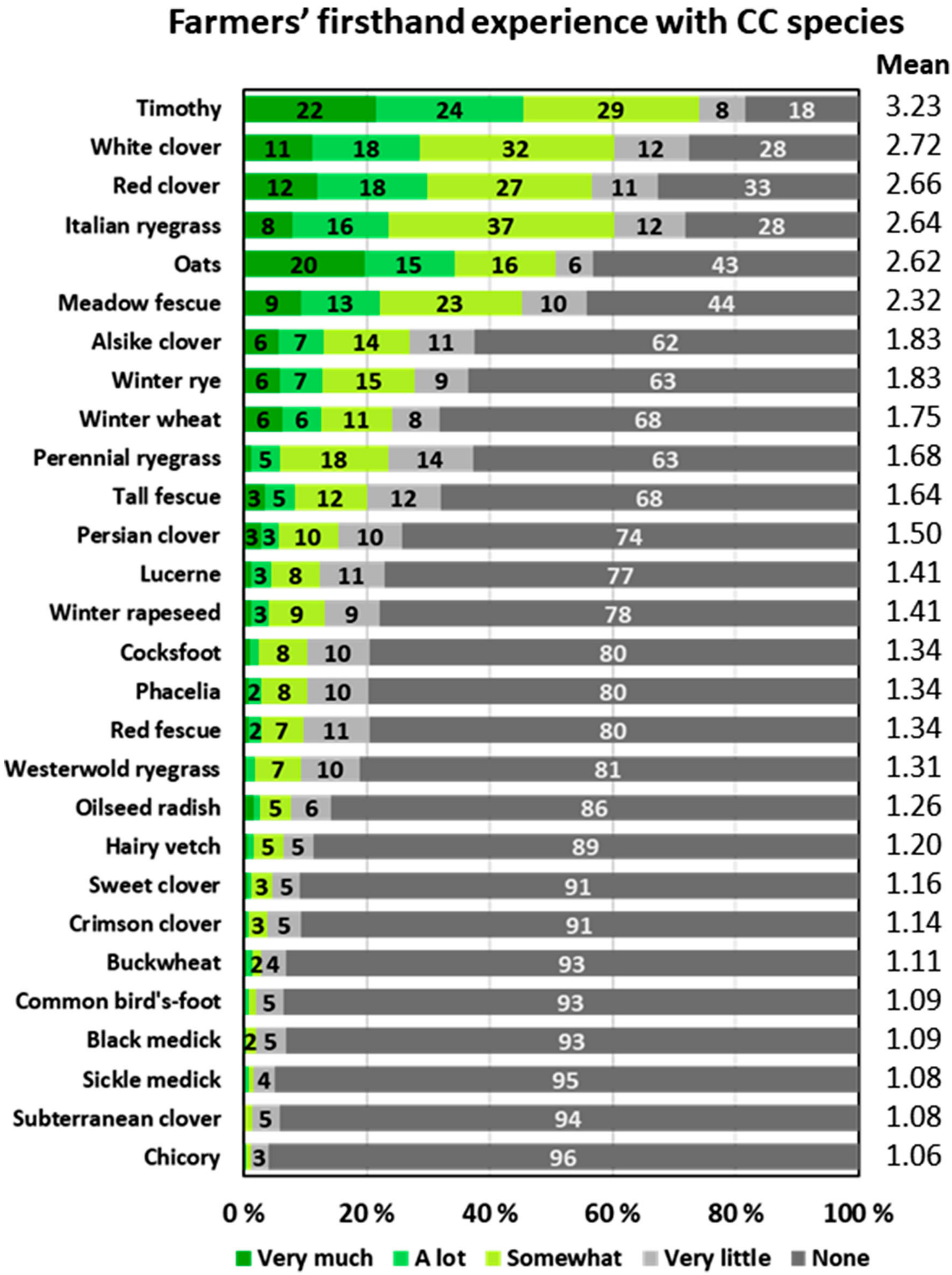

Figure 1. The distribution and mean (in order of decreasing value) of farmers' answers ($N = 1130$) to the question *Which cover crops (CCs) do you have first-hand experience with?* The answer choices were: 1 = none, 2 = very little, 3 = somewhat, 4 = a lot and 5 = very much. The share of each answer choice is shown within each bar except in the case of being ≤1%.

available for the question of experience with mixtures. The questionnaire is shown in Table S1 (translated from Finnish/Swedish to English).

In total 1130 farmers answered the survey, which corresponded to a 17.4% response rate. An additional 362 viewed or started to fill in the survey without completing and returning it by the deadline. The survey respondents had to answer all the questions of the survey to be able to return their answers.

Only the farmer's age (≤30, 31–50, 51–70 and >70 years) and education (basic, vocational, college level and university) were requested as background information in the survey. Because the shares of farmers ≤30 and >70 years were low, as was also the case in this survey, these age groups were merged with the adjacent ones to form two age groups of ≤50 years and >50 years. The background information that was not requested in the survey was available for 2020 in the registry of the FFA by using the farm identity number. After merging the datasets, the respondents were grouped for statistical analyses according to: (1) the farming system (organic and conventional) they operated, (2) the farm type they operated (cereal, special crop, horticulture, cattle, pig, poultry and horse/sheep farm), (3) the farm size (<40, 40–79, 80–119 and ≥120 ha) and (4) the geographical region their farms were located in (merging 16 Centers for Economic Development, Transport and the Environment, ELY Centers to form four main regions: South-, West-, East/North-Finland and the inland region). Furthermore, for each responding farm the share of land devoted for cereals, grassland, special crops [peas (*Pisum sativum* L.), faba beans (*Vicia faba* L.), spring and winter oilseed rape (*Brassica napa* L.) and turnip rape (*B. rapa* L.), caraway (*Carum carvi* L.)] and other crops [e.g. potatoes (*Solanum tuberosum* L.) and sugar beets (*Beta vulgaris* var. *altissima*] were assembled from the registry of the FFA and grouped as <25%, 25–50% and ≥50% for cereals, grasslands and other crops, and as 0%, < 10% and ≥10% for special crops due to their low cultivation areas.

2.2. Statistical analyses

According to the preliminary examination, answers of all the 1130 respondents were considered acceptable and were used for statistical analyses. Non-response biased was assessed by comparing characteristics of the respondents who returned the survey to those of non-respondents. The compared characteristics were: the region, farming system, farm type, farm size, farm cereal area, grassland area, special crop area and other crop area. No significant distortions of representativeness were found. The response rate was close to that of the contacted farmers (i.e. 17.4% ± ~2%) for regions, farm sizes, the shares of land devoted to different crop groups in a farm and for organic and conventional farms (232 and 898 responses, respectively). Considering farm types, the cattle farms and pig farms were slightly, but not significantly underrepresentative (Table S2). Non-response bias did not occur or was insignificant and therefore, no methods to take bias into account were needed.

A Cochran–Mantel–Haenszel test (CMH) was used to test the relationship between the row and column variables. The row variables were formed from eight characteristics of the respondents (e.g. the region, farming system, farm type and farm size) and the column variables were the results of the farmers' cultivation experience with 28 different CCs (Figure 1) indicated with a 5-point Likert scale. Typically, row and column variables were ordinal scale and the correlation statistic of the CMH with 1 degree of freedom was used. If a row variable was not an ordinal scale as in the case of region and farm type, ANOVA (Row Mean Scores, RMS) statistics for the CMH was used. ANOVA (RMS) tests were used for all pairwise comparisons, as well as when testing the interaction between the farming system and other characteristics of respondents (data not shown, except in Table S3). All CMH tests were performed using SAS/FREQ and SAS/GLM procedures (Stokes et al., 2001).

The number of CCs that a farmer had first-hand experience with was defined as a sum of species for which the respondent had 'somewhat', 'a lot' or 'very much' experience. For the statistical analysis, respondents were classified into three groups (1–5, 6–10 and ≥11 CCs). After that, all statistical analyses were based on the CMH and ANOVA tests. In addition, the average from the original answers was calculated over all CCs and respondents. The mean and maximum were calculated from each respondent's data. These statistics were presented descriptively, testing was not done.

3. Results

3.1. Cover crops used by Finnish farmers

Finnish farmers had at least some cultivation experience with a high number of CCs (Figure 1).

However, the average rating over all CCs was only 1.64. This was attributable to a high number of CCs in the questionnaire, while only part of CCs was very familiar to respondents. There were in total 31,640 answers (1130 respondents and 28 CC species): 71% of respondents rated 1 = none experience, 8% 2 = very little, 11% 3 = somewhat, 6% 4 = a lot and 4% 5 = very much. However, the average varied greatly among CCs. Less than 2% of the respondents cultivated CCs first time and had no experience yet.

Farmers were mostly experienced with CCs that were commonly used in annual or perennial grasslands, environmental fallows or as grain crops. The mean value of answers exceeded 3.0 only in the case of timothy (*Phleum pratense* L.) and 2.0 for white clover (*Trifolium repens* L.), red clover (*T. pratense* L.), Italian ryegrass (*Lolium multiflorum* L.), oats (*Avena sativa* L.) and meadow fescue (*Festuca pratensis* L.). Other grain crops that were used as CCs were winter rye (*Secale cereale* L.), winter wheat (*Triticum aestivum* L.), winter rapeseed and buckwheat (*Fagopyrum esculentum* L.). Less than 10% of farmers had used sweet clover, crimson clover (*T. incarnatum* L.) and buckwheat as CCs. Common bird's-foot trefoil (*Lotus corniculatus* L.), black medick (*Medicago lupulina* L.), sickle medick (*M. falcata* L.), subterranean clover (*T. subterraneum* L.) and chicory (*Cichorium intybus var. sativum* L.) were species that hardly any of the respondents had cultivation experience with. Only 11% of respondents had very much or a lot experience of using CCs as mixtures, while 28% had very little and 33% none.

3.2. Differences between farming systems, farm types, farm sizes and regions on cultivated cover crops

The number of CCs that farmers had first-hand experience varied according to farm characteristics. Organic producers, farmers with larger farms and cattle farms had experience with a higher number of CCs (Figure 2). Farmers were more experienced with CC mixtures in South-Finland, as was the case for organic producers (Figure 3).

Organic farmers had more experience than conventional farmers in the cultivation of all the other CC species (Figure 4) except winter wheat, oilseed radishes (*Raphanus sativus var. oleiferus* L.) and phacelia (*Phacelia tanacetifolia* L.). The difference between organic and conventional farmers was especially high for red clover and alsike clover (*T. hybridum* L.). There were some differences between farm types on CCs species that were used (Tables 1 and 2). For example, cattle farms were more experienced with perennial grasses as CCs contrary to less common species like phacelia, oilseed radishes, buckwheat and sweet clover. Cereal and special crop farms also favoured common grassland crops such as red clover, timothy, meadow fescue and Italian ryegrass as CCs. Horse/sheep and horticulture farms came up as farm types with experience with some very rarely used CCs such as lucerne (*Medicago sativa* L.), common bird's-foot trefoil and sickle medick.

The choices of CCs varied depending on farm size (Table 3). Larger farms (≥80 ha) tended to be more experienced than smaller farms with white clover, Italian ryegrass, winter wheat, winter rye, tall fescue (*Festuca arundinaceae* L.), winter rapeseed and oilseed radishes. Many differences between regions were found on farmer's CC choices (Table 1). For example, farmers in South-Finland favoured Italian ryegrass, winter rye, winter wheat, winter rapeseed and buckwheat more frequently than those with farms elsewhere, which was the opposite to timothy.

3.3. Cover crop choices depending on land use in a farm

Farmers with higher shares of land area used as grassland and other crops, and lower shares of cereals had experience with a higher number of CCs (Figure 2). Farmers were more experienced with CC mixtures when they had larger areas of grassland or other diversifying crops and low areas of cereals (Figure 3). Farmers who had a high share of cereal area on a farm (>50%) used winter wheat as a CC, while those with ≤50% of cereal area used many other CCs that are common as cash and grass crops. In the case of larger grassland areas on a farm, farmers used more frequently grass and leguminous crops as CCs, but less often winter rye, winter wheat, winter rapeseed, oilseed radishes and phacelia.

In Finland, the total land area under special crops is in general small – especially, when compared to that for cereals and grass crops. However, farmers with even some land area under special cash crops (e.g. legumes and rapeseed) were more experienced with winter rye, winter wheat and winter rapeseed when compared to those who did not cultivate any special cash crops (Table 1). Experience with CCs varied depending on the share of field area dedicated to a diverse group of other crops (especially potatoes

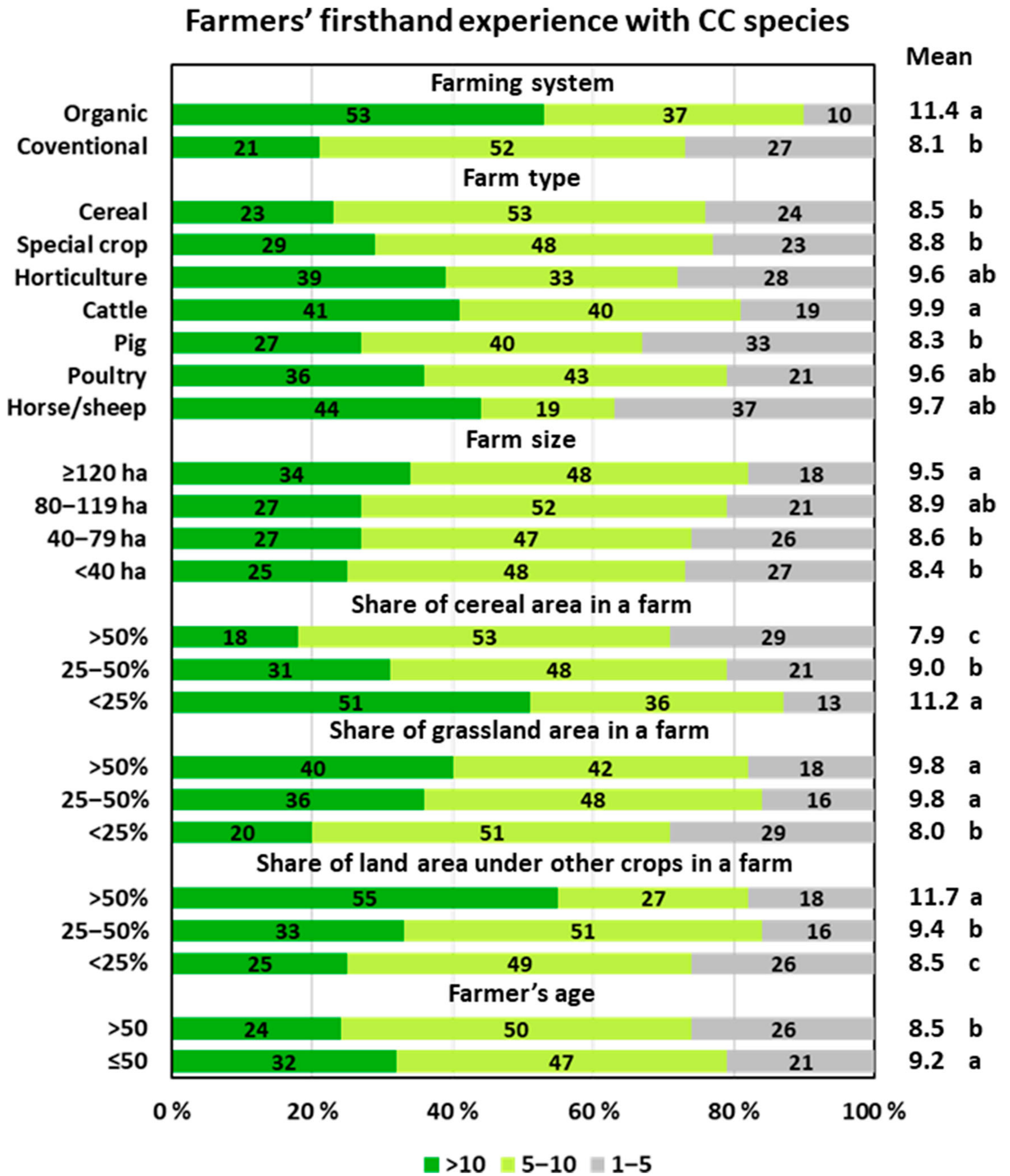

Figure 2. The distribution of the number of cover crop (CC) species grown by farmers when grouped into three categories (1–5, 6–10 and ≥11 CCs) depending on farm characteristic. Only such CC species were included that farmer had very much or a lot of first-hand experience. Mean value is, however, based on original, non-grouped numbers of CC species. The share of each answer choice is shown within each bar. Means for groups within each farm characteristic with the same letter do not differ significantly from each other (at $P \leq 0.05$).

and sugar beet). Farmers with higher areas under these crops were often more experienced than those with low areas (<25%) with many grass CCs as well as with oilseed radishes, buckwheat, phacelia and a high number of leguminous CCs (Tables 1 and 2).

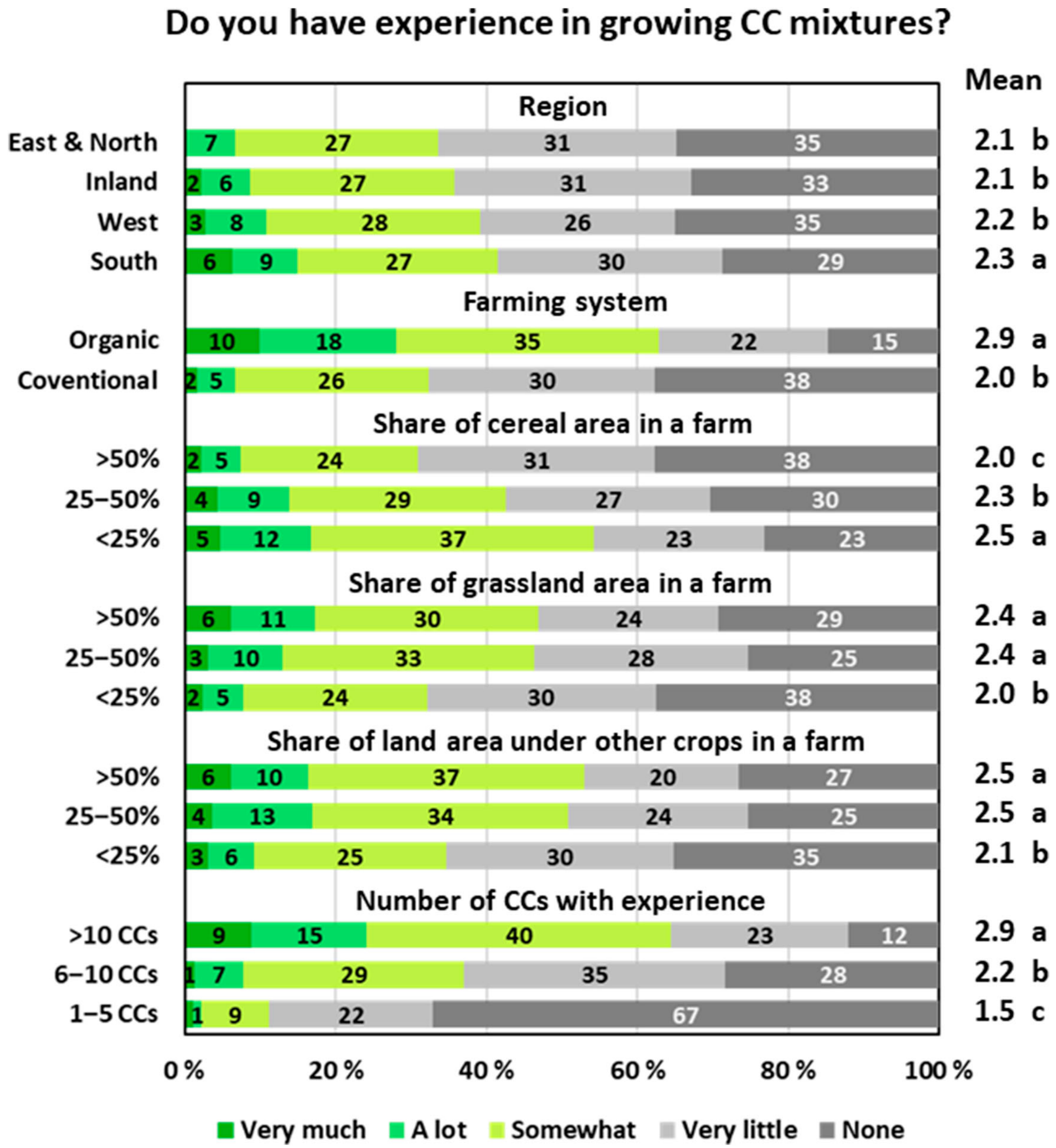

Figure 3. The distribution and mean value for farmers' answers to the question *Do you have experience in growing cover crops (CCs) as mixtures?* depending on region, farming system, share of land area under cereals, grassland, and other types of diversifying crops (e.g. potatoes and sugar beet) as well as the number of CC species farmer were experienced. The answer choices were: 1 = none, 2 = very little, 3 = somewhat, 4 = a lot and 5 = very much. The share of each answer choice is shown within each bar. Means with the same letter do not differ significantly from each other (at $P \leq 0.05$).

3.4. Farmer's cover crop preferences depending on age and education

Younger farmers had experience with a higher number of CC species (Figure 2). In general, differences between the two age groups were modest (Figure 5). In the case of white clover, oats, winter rye, winter wheat, tall fescue, lucerne and winter rapeseed, younger farmers (≤50 years) had more experience than the older farmers. The farmers' experience with different CCs was often dependent on their education.

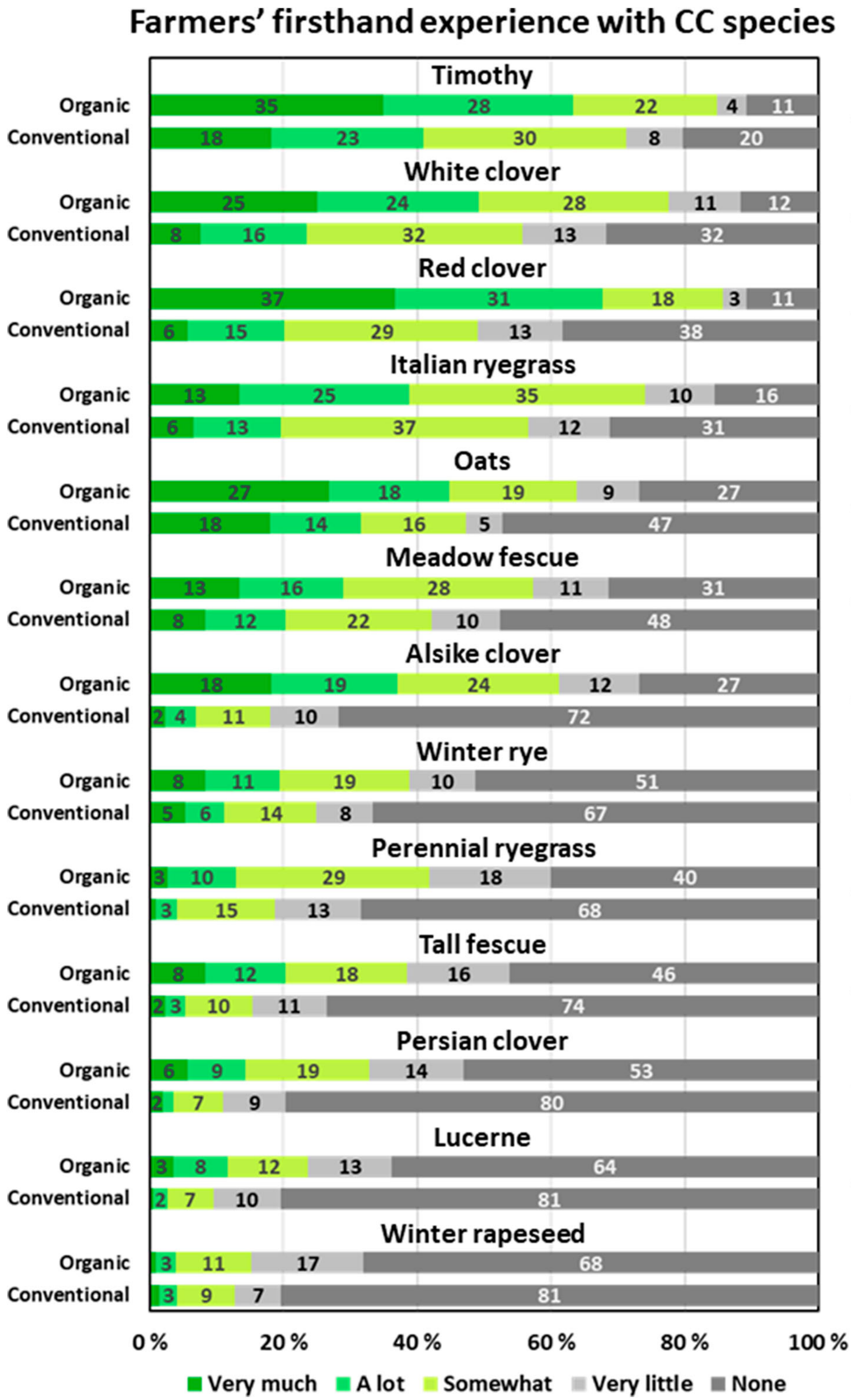

Figure 4. The distribution of the most commonly used cover crop (CC) species in Finland depending on farming system. The share of each answer choice is shown within each bar except in the case of being ≤1%. NZC, nonzero correlation, i.e. a statistical test that tests the difference between two distributions.

Table 1. Differences in farmers' experiences with various conventional crops as CCs depending on farm characteristics ($N = 1130$). Means with the same latter do not differ significantly from each other (at $P \leq 0.05$). Number of respondents depending on farm characteristics is shown in Table S2.

Farm characteristic	Italian ryegrass	Perennial ryegrass	Westerwold ryegrass	Timothy	Meadow fescue	Red fescue	Tall fescue	Cocksfoot	Winter rye	Winter wheat	Oats	Winter rapeseed	Oilseed radish	Buckwheat
Region														
South	2.86 a	1.61 a	1.24 b	2.74 c	2.21 b	1.39 a	1.70 a	1.34 a	2.21 a	2.34 a	2.32 b	1.58 a	1.36 a	1.21 a
West	2.56 b	1.69 a	1.37 a	3.45 a	2.26 b	1.29 a	1.59 b	1.32 a	1.69 b	1.48 b	2.79 a	1.36 b	1.27 ab	1.09 b
Inland	2.60 b	1.71 a	1.25 b	3.19 b	2.39 b	1.37 a	1.60 b	1.39 a	1.77 b	1.82 c	2.59 a	1.37 b	1.19 bc	1.07 b
East-North	2.45 b	1.76 a	1.33 ab	3.60 a	2.85 a	1.36 a	1.87ab	1.35 a	1.63 b	1.19 d	2.67 ab	1.21 b	1.10 c	1.06 b
Farm type														
Cereal	2.62 b	1.59 bc	1.24 b	3.09 bc	2.06 b	1.28 c	1.43 b	1.27 bc	1.93 ab	1.82 bc	2.54 a	1.46 bc	1.20 de	1.12 ab
Special crop	2.71 b	1.48 c	1.24 b	3.09 bc	2.30 b	1.33 bc	1.51 b	1.25 bc	1.93 ab	1.79 bcd	2.63 a	1.35 bcd	1.69 b	1.19 a
Horticulture	2.17 b	1.72 abc	1.50 ab	3.17 bc	2.50 b	1.28 abc	1.44 b	1.22 bc	1.44 bc	1.33 de	3.17 a	1.17 cd	2.17 a	1.22 ab
Cattle	2.68 b	2.10 a	1.54 a	3.84 a	3.29 a	1.51 a	2.42 a	1.68 a	1.44 c	1.40 e	2.80 a	1.21 d	1.09 e	1.04 b
Pig	2.55 b	1.70 bc	1.27 b	2.76 c	1.82 b	1.55 ab	1.48 b	1.06 c	1.79 abc	2.18 ab	2.30 a	1.45 bcd	1.42 bc	1.15 ab
Poultry	3.43 a	1.50 bc	1.21 ab	3.00 bc	2.43 b	1.36 abc	1.79 b	1.57 ab	2.36 a	2.86 a	3.29 a	2.21 a	1.36 bcd	1.00 ab
Horse/Sheep	2.25 b	2.00 ab	1.50 ab	3.69 ab	2.31 b	1.25 abc	1.81 b	1.31 abc	1.94 abc	1.38 cde	2.63 a	1.75 ab	1.25 cd	1.13 ab
Cereal area														
<25%	2.95 a	2.21 a	1.71 a	3.76 a	3.03 a	1.56 a	2.24 a	1.58 a	1.73 a	1.52 b	2.89 a	1.46 a	1.44 a	1.27 a
25–50%	2.60 b	1.74 b	1.30 b	3.49 b	2.61 b	1.32 b	1.82 b	1.38 b	1.83 a	1.60 b	2.69 ab	1.33 a	1.26 b	1.09 b
>50%	2.55 b	1.47 c	1.18 c	2.89 c	1.92 c	1.28 b	1.33 c	1.24 c	1.86 a	1.91 a	2.48 b	1.43 a	1.20 b	1.08 b
Grassland area														
<25%	2.63 a	1.49 c	1.19 c	2.81 b	1.90 b	1.28 b	1.34 c	1.21 b	1.91 a	1.96 a	2.42 b	1.46 a	1.32 a	1.11 a
25–50%	2.69 a	1.83 b	1.34 b	3.74 a	2.76 a	1.35 ab	1.89 b	1.49 a	1.90 a	1.59 b	2.85 a	1.40 ab	1.22 ab	1.17 a
>50%	2.58 a	2.01 a	1.56 a	3.76 a	2.95 a	1.47 a	2.13 a	1.53 a	1.55 b	1.36 c	2.88 a	1.26 b	1.16 b	1.07 a
Special crop area														
0%	2.55 b	1.74 a	1.34 a	3.39 a	2.44 a	1.37 a	1.69 a	1.39 a	1.58 b	1.50 b	2.72 a	1.25 b	1.24 a	1.11 a
<10%	2.76 ab	1.62 ab	1.23 ab	3.22 a	2.41 a	1.24 a	1.68 ab	1.41 a	2.33 a	2.23 a	2.75 a	1.73 a	1.28 a	1.11 a
>10%	2.78 a	1.57 b	1.25 b	2.86 b	2.02 b	1.30 a	1.51 b	1.21 b	2.20 a	2.13 a	2.33 b	1.64 a	1.30 a	1.13 a
Other crop area														
<25%	2.56 b	1.62 b	1.27 c	3.18 a	2.25 b	1.31 b	1.59 b	1.32 a	1.85 a	1.80 a	2.60 a	1.41 a	1.17 c	1.08 c
25–50%	2.83 a	1.82 a	1.38 b	3.38 a	2.48 a	1.36 b	1.75 a	1.40 a	1.77 a	1.58 b	2.66 a	1.36 a	1.47 b	1.17 b
>50%	3.00 a	2.10 a	1.69 a	3.37 a	2.84 a	1.67 a	1.98 a	1.43 a	1.80 a	1.57 ab	2.67 a	1.53 a	1.98 a	1.49 a

Table 2. Differences in farmers' experiences with various special CCs depending on farm characteristics ($N = 1,130$). Means with the same latter do not differ significantly from each other (at $P \leq 0.05$). Number of respondents depending on farm characteristics is shown in Table S2.

Farm characteristic	Red clover#	White clover	Alsike clover*#	Persian clover	Crimson clover	Subterranean clover	Sweet clover*	Black medick	Sickle medick	Lucerne*	Common bird's-foot	Hairy vetch	Phacelia*	Chicory
Farm type														
Cereal	2.61 a	2.72 a	1.67 b	1.47 a	1.14 a	1.07 a	1.16 a	1.08 a	1.06 b	1.33 b	1.07 c	1.16 cde	1.36 b	1.06 a
Special crop	2.68 ab	2.53 a	1.72 b	1.53 a	1.15 a	1.07 a	1.20 abc	1.10 a	1.06 ab	1.33 b	1.08 bc	1.22 be	1.50 a	1.04 a
Horticulture	2.94 ab	3.11 a	2.00 ab	1.67 a	1.11 a	1.06 a	1.44 a	1.11 a	1.17 ab	1.56 ab	1.17 bc	1.67 a	1.56 ab	1.00 a
Cattle	2.88 a	2.86 a	2.41 a	1.54 a	1.17 a	1.09 a	1.07 bc	1.11 a	1.14 a	1.63 a	1.17 b	1.29 b	1.14 c	1.07 a
Pig	2.18 b	2.82 a	1.52 b	1.48 a	1.12 a	1.12 a	1.06 c	1.18 a	1.06 ab	1.42 ab	1.03 bc	1.03 de	1.42 ab	1.03 a
Poultry	2.36 ab	2.43 a	2.14 ab	1.64 a	1.21 a	1.07 a	1.36 ab	1.21 a	1.14 ab	1.64 ab	1.07 bc	1.14 bcde	1.21 abc	1.07 a
Horse/Sheep	2.50 ab	2.50 a	2.13 ab	1.38 a	1.25 a	1.06 a	1.38 abc	1.19 a	1.25 a	1.88 a	1.50 a	1.38 abcd	1.38 abc	1.13 a
Cereal area														
<25%	3.28 a	3.08 a	2.69 a	1.82 a	1.35 a	1.13 a	1.34 a	1.18 a	1.17 a	1.78 a	1.28 a	1.43 a	1.46 a	1.16 a
25–50%	2.97 b	2.72 b	1.96 b	1.53 b	1.11 b	1.06 b	1.14 b	1.09 b	1.08 b	1.43 b	1.08 b	1.19 b	1.33 ab	1.05 b
>50%	2.26 c	2.61 b	1.47 c	1.37 c	1.10 b	1.06 b	1.11 b	1.07 b	1.05 b	1.28 c	1.04 b	1.13 b	1.31 b	1.02 b
Grassland area														
<25%	2.27 b	2.59 b	1.49 c	1.39 b	1.10 b	1.05 b	1.15 a	1.07 b	1.04 b	1.28 b	1.05 b	1.15 b	1.36 a	1.03 b
25–50%	3.15 a	2.86 a	2.08 b	1.57 a	1.19 a	1.13 a	1.19 a	1.13 a	1.15 a	1.63 a	1.14 a	1.25 a	1.40 a	1.07 ab
>50%	3.13 a	2.93 a	2.43 a	1.68 a	1.21 a	1.09 ab	1.15 a	1.12 ab	1.09 ab	1.49 a	1.16 a	1.27 a	1.23 b	1.10 a
Other crop area														
<25%	2.56 b	2.71 a	1.74 b	1.45 b	1.11 b	1.07 a	1.12 b	1.08 b	1.06 b	1.35 b	1.07 b	1.15 b	1.28 c	1.04 b
25–50%	2.94 a	2.73 a	2.05 a	1.56 b	1.24 a	1.09 a	1.20 b	1.11 b	1.06 b	1.56 a	1.15 a	1.34 a	1.48 b	1.11 a
>50%	3.22 a	2.92 a	2.43 a	2.02 a	1.37 a	1.16 a	1.61 a	1.24 a	1.37 a	1.71 a	1.24 a	1.43 a	1.84 a	1.12 ab

*Farmers in South-Finland were most experienced with sweet clover, lucerne and phacelia, while those in North-Finland with alsike clover.
#Farmers were less experienced with red clover and alsike clover if they had >10% of field area on special crops.

Table 3. Differences in farmers' experiences with various CCs depending on farm size and farmer's education ($N = 1130$). Means with the same latter do not differ significantly from each other (at $P \leq 0.05$). Number of respondents depending on farm size and farmer's education are shown in Table S2.

Farm and farmer characteristic	Italian ryegrass	Timothy	Tall fescue	Winter rye	Winter wheat	Oats	Winter rapeseed	Oilseed radish	White clover	Subterranean clover	Hairy vetch	Phacelia
Farm size												
<40 ha	2.48 b	3.28 a	1.44 c	1.57 c	1.33 d	2.71 a	1.21 c	1.20 b	2.68 b	1.09 a	1.25 a	1.37 a
40–79 ha	2.52 b	3.22 a	1.61 b	1.72 bc	1.66 c	2.57 a	1.36 b	1.18 b	2.63 b	1.06 a	1.17 a	1.31 a
80–119 ha	2.80 a	3.20 a	1.84 a	1.91 b	1.89 b	2.54 a	1.39 b	1.35 a	2.75 ab	1.07 a	1.21 a	1.34 a
≥120 ha	2.87 a	3.19 a	1.77 ab	2.25 a	2.28 a	2.62 a	1.72 a	1.38 a	2.90 a	1.08 a	1.16 a	1.36 a
Farmer's education												
Basic	2.45 b	3.44 a	1.36 a	1.55 b	1.30 c	2.84 a	1.23 c	1.20 a	2.49 b	1.15 a	1.21 ab	1.29 b
Vocational	2.51 b	3.35 a	1.70 a	1.73 b	1.67 b	2.72 a	1.36 bc	1.23 a	2.61 b	1.09 a	1.15 b	1.28 ab
College level	2.84 a	3.07 b	1.60 a	1.83 b	1.71 b	2.37 b	1.45 ab	1.29 a	2.84 a	1.02 b	1.21 ab	1.38 ab
University	2.73 ab	3.10 b	1.64 a	2.08 a	2.04 a	2.57 ab	1.49 a	1.31 a	2.89 a	1.07 ab	1.27 a	1.44 a

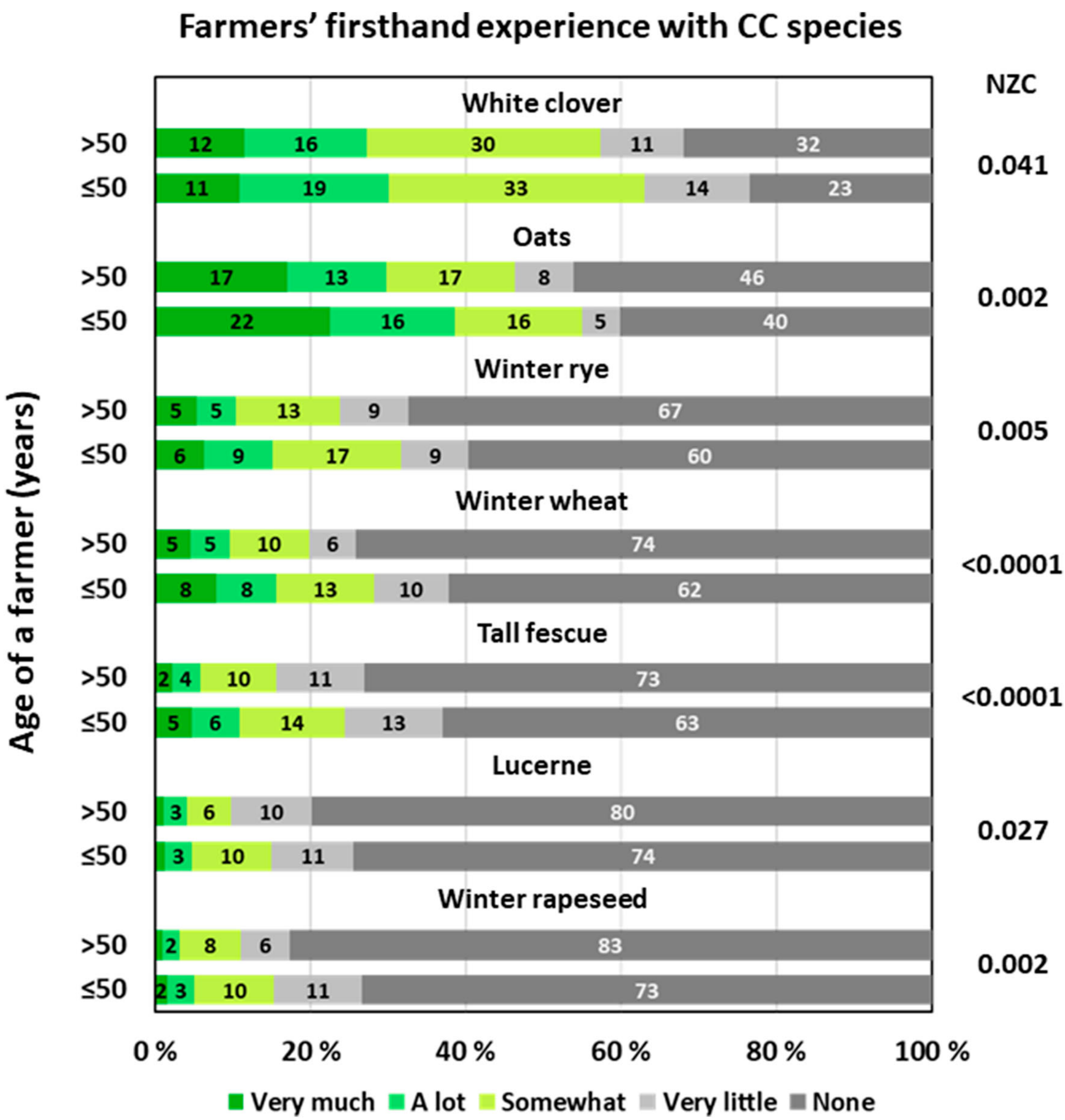

Figure 5. The distribution of cover crop (CC) species grown by farmers depending on farmer's age group. The share of each answer choice is shown within each bar except in the case of being ≤1%. NZC, nonzero correlation, i.e. a statistical test that tests the difference between two distributions.

Farmers with higher education (university and/or college level) had more experience than those with a lower education with CCs like white clover, Italian ryegrass, winter cash crops as CCs and phacelia (Table 3). The situation was the opposite for very common crops as CCs such as timothy and oats for which farmers with basic and vocational education were more experienced. For other CCs the differences were minor. The farming system × education interaction was significant for quite many CCs: the level of education did not have any impact on the experience of conventional farmers with CCs contrary to that of organic ones (Table S3). For example, for organic farmers there was a systematic increasing trend of experience with perennial ryegrass (*Lolium perenne* L.), sickle medick and buckwheat with higher education.

4. Discussion

This survey revealed that a high number of CC species have been used or at least tested by Finnish farmers despite the low total field areas under CCs and exceptionally short growing season (Peltonen-Sainio et al., 2016; Peltonen-Sainio & Jauhiainen, 2020) that may limit the CC choices available in Finland compared to more southern regions. In general, crop choices and their cultivation areas have increased in Finland with climate warming (Peltonen-Sainio & Jauhiainen, 2020; Zhao et al., 2022), which may similarly make more diverse choice of successfully grown CCs available for farmers. According to Aronsson et al. (2016), contrary to Denmark (8%) and Sweden (5%), CCs were grown only on 1% of arable land in Finland, although a dramatical increase in the trend was recognized. In a recent study, CCs were anticipated to exhibit a substantial, so far underused expansion potential on Finnish farms: only 14% of area considered to be suitable are currently used for CCs. The potential expansion is even higher on conventional farms, where CCs were grown on only 6% of the total field area compared to 10% in organic farms. Despite a surprisingly diverse choice of CCs, farmers mainly used CCs that are also commonly cultivated primary crops.

4.1. Region and farm type shape farmer's cover crop choices

Finland is a long, high-latitude country in a cold-temperate/boreal vegetation zone and hence, prerequisites for cultivating crops differ substantially depending on region (Peltonen-Sainio & Jauhiainen, 2020). This also agreed with the farmers' CCs choices, which may be partly attributable to the polarization of certain farm types in specific regions in Finland, reinforced by long-term regional policies. Especially dairy production and thereby perennial grasslands are common in East- and North-Finland, while the production of grain and seed crops dominates land use in South- and West-Finland (Peltonen-Sainio & Jauhiainen, 2020). Hence, the farmer's CC preferences differed depending on the share of grassland and cereal area in a farm. This was not likely only attributable to the general suitability of different CCs for the existing production system and cash crops (Peltonen-Sainio et al., 2022a), but also to the farmer's earlier experience in cultivating certain species. For example, in the case of larger grassland areas on a farm, farmers were more experienced with many grass crops and clover species as CCs, but less so with species like winter rye, winter wheat and winter rapeseed. The latter species as well as buckwheat (a minor pseudo-cereal) are mainly grown as cash crops in southern, crop production dominated regions (Peltonen-Sainio & Jauhiainen, 2020).

Some more differences in CC choices were found between farm types. For example, in cereal and special crop farms common grassland crops were favoured as CCs. In pig farms nitrogen-fixing leguminous CCs were avoided, which may be partly attributable to on-farm use of pig slurry for crop nutrition. Even though farmers tended to often favour familiar crops as CCs, depending on farm type, they may have very specific motives for choosing some exceptional CCs (Thorup-Kristensen & Rasmussen, 2015). For example, deep-rooted oilseed and fodder radish are used as catch- and break-crops in cereal-dominated land areas (Munkholm & Hansen, 2012) – recently also in Finland. Crucifers may catch nitrogen (Tuulos et al., 2015) and sulfur (Couëdel et al., 2018) and suppress soil-borne pathogens (Hossain et al., 2012). Phacelia is grown also in Finland for various purposes such as soil cover, landscaping and honey production. Chicory, common bird's-foot trefoil, crimson clover and subterranean clover were among the most exotic CCs tested by Finnish farmers. Increasing functional diversity by growing mixtures of CCs is a potential means to modify amount and timing of nitrogen release (Furey et al., 2021). Subterranean clover was a very exotic species for Finnish farmers, while commonly grown in a Mediterranean climate (Pecetti et al., 2020; Teixeira et al., 2021).

4.2. Farmers with diverse land use and higher education tended to have more diverse cover crop choices

Farmers were most experienced with CCs that are well-known primary crops in Finland, with large-scale, established management practices and knowhow on their growth performance and production risks. The use of familiar species as CCs does not necessarily increase species diversity at the farm or regional scale, even though CCs are likely to increase spatial diversity on the field parcel scale, e.g. in the case of under-sowing clover for cereals. Nonetheless, farmers have already gained some experience with quite a number of alternative CCs, but many of them were piloted only by a few respondents. Even though farmers' views on the benefits that CCs may provide for production, sustainability, resilience and the environment did not largely differ in Finland depending on education (Peltonen-Sainio et al., 2022b), under 50 years old respondents and those with a university- and/or college-level education tended to be more open to exploring alternative CCs on their farms. Educated farmers had, e.g. some experience with winter cereals and rapeseed, white clover, and phacelia, and higher educated organic farmers also with rarely used sickle medick and buckwheat. In Finland, organic farmers have far more diverse land use than conventional producers (Peltonen-Sainio & Jauhiainen, 2019) and they were more experienced with both common and some rarely used leguminous CCs like sweet clover, crimson clover, common bird's-foot trefoil and medicks. These rarely used CCs were virtually unexperienced species on conventional farms. Organic producers do not have to pay attention to the herbicide sensitivity of under-sown CCs, which also allows use of CC mixtures. Leguminous CCs have underutilized potential especially in conventional cereal farms (Peltonen-Sainio & Jauhiainen, 2019) to fix nitrogen and support nutrient cycling (De Notaris et al., 2020).

The area under different groups of primary crops on a farm substantially affected the degree of experience that farmers had with CCs. Especially farmers with a higher share of land under other types of diversifying crops like potatoes and sugar beet had used or tested higher number of CC species. On the other hand, farmers with higher share of field area on special crops, grain legumes and rapeseed, did not use more frequently special CCs than other farmers. Our findings highlight the need to share knowledge on CCs with farmers having cereals dominated farms to encourage the transition towards higher land use diversity and more resilient and sustainable systems (Poeplau & Don, 2015; Stoate et al., 2009), especially, as Finnish farmers agreed that CCs are the means to gain such improvements (Peltonen-Sainio et al., 2022b).

Finnish farmers were not yet familiar with using CCs as mixtures. Only 11% of the respondent answered that they had very much or a lot of experience with use of CC mixtures, while 28% had very little and 33% no experience at all. The use of mixtures may e.g. boost simultaneous, divergent benefits provided by CCs (Blanco-Canqui et al., 2015; Daryanto et al., 2018; Furey et al., 2021). The use of mixtures of CCs may also reduce the risk of choosing a poorly performing single species that does not grow successfully in the case of unfavourable weather conditions – often due to the high condition-dependency of CCs (Vincent-Caboud et al., 2017; Wittwer & van der Heijden, 2020). Mixtures were more frequently used by organic producers and on farms located in South-Finland, farms with higher land areas dedicated to grassland and other crops (e.g. potatoes and sugar beet), lower land areas dedicated to cereals, and in cases when farmers had experience with a higher number of CCs. A practical reason for choosing sole crops as CCs can be that their seed is for sale virtually everywhere in contrast to seed mixtures. The experience gained especially by organic farmers in cultivating CCs as mixtures is valuable and needs to be shared with all Finnish farmers.

The future expansion of CCs may be further pushed by climate change, as has already taken place with many minor cash crops (Peltonen-Sainio & Jauhiainen, 2020). Expanding CC cultivation areas and becoming familiar with their use in cropping systems may, however, face many region- and management-specific challenges that should not be overlooked (Blanco-Canqui et al., 2015; Daryanto et al., 2018; Sieling, 2019). Finnish farmers agreed with this even though they were mostly positive about the potential benefits that CCs may bring for high-latitude crop production systems (Peltonen-Sainio et al., 2022b). Region-specific farmer surveys like this, focusing on farmers' experiences with CCs facilitate open dialogue within the farmer–researcher–advisor community. This is important in countries like Finland where farmers' interest in CCs has increased dramatically. Although experiences with some diversifying CCs are still scarce in Finland, our findings suggest that farmers who cultivate other cash crops than cereals tend to be more open to piloting CCs that are not yet largely in use.

5. Conclusion

This survey revealed that Finnish farmers were experienced overall with a high number of CC species considering the limitations that high-latitude conditions set for primary crop species and how underutilized CCs are so far. Farmers used CCs mainly as monocrops. Only 11% of the respondents had a great amount of experience with CC mixtures. Farmers were especially experienced with CCs that are already familiar to them as primary crops. However, the differences between farming systems were significant, and organic producers were usually more experienced with both common and less frequently used CCs. This is likely to be attributable to an appreciation of the variety of potential ecosystem services that CCs may provide – as well as the reduced need to consider herbicide damage. In addition, more educated farmers tended to be more open to exploring alternative CC species and their share in farmer community has increased over time. Farmers with diversity-oriented farms using more diverse CC species are important pioneers to share knowhow and best CC-practices among the farming community. Especially farmers who have cereal-based systems (spring cereal mono-cropping) are an important target group for knowledge sharing and policy instruments.

Acknowledgements

This work was financed by Ministry of Agriculture and Forestry of Finland, project *Evergreen Revolution with Cover Crops – Best Practices to Enhance C Sequestration (IKIVIHREÄ)*, grant number VN/5082/2021-MMM-2 (*Catch the Carbon* program) and Luke's strategic funding on project *Farmer-specific methods to sustainably intensify agricultural systems by closing yield gaps (F-Specific)*.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by Maa- ja Metsätalousministeriö (Ministry of Agriculture and Forestry of Finland): [Grant Number VN/5082/2021-MMM-2].

ORCID

Pirjo Peltonen-Sainio http://orcid.org/0000-0002-1083-2201

References

Adetunji, A. T., Ncube, B., Mulidzi, R., & Lewu, F. B. (2020). Management impact and benefit of cover crops on soil quality: A review. *Soil and Tillage Research*, *204*, 104717. https://doi.org/10.1016/j.still.2020.104717

Aronsson, H., Hansen, E. M., Thomsen, I. K., Liu, J., Øgaard, A. F., Känkänen, H., & Ulén, B. (2016). The ability of cover crops to reduce nitrogen and phosphorus losses from arable land in southern Scandinavia and Finland. *Journal of Soil and Water Conservation*, *71*(1), 41–55. https://doi.org/10.2489/jswc.71.1.41

Blanco-Canqui, H., Shaver, T. M., Lindquist, J. L., Shapiro, C. A., Elmore, R. W., Francis, C. A., & Hergert, G. W. (2015). Cover crops and ecosystem services: Insights from studies in temperate soils. *Agronomy Journal*, *107*(6), 2449–2474. https://doi.org/10.2134/agronj15.0086

Costantini, E. A. C., Antichi, D., Almagro, M., Hedlund, K., Sarno, G., & Virto, I. (2020). Local adaptation strategies to increase or maintain soil organic carbon content under arable farming in Europe: Inspirational ideas for setting operational groups within the European innovation partnership. *Journal of Rural Studies*, *79*, 102–115. https://doi.org/10.1016/j.jrurstud.2020.08.005

Couëdel, A., Alletto, L., & Justes, É. (2018). Crucifer-legume cover crop mixtures provide effective sulphate catch crop and sulphur green manure services. *Plant and Soil*, *426*(1-2), 61–76. https://doi.org/10.1007/s11104-018-3615-8

Daryanto, S., Fu, B., Wang, L., Jacinthe, P., & Zhao, W. (2018). Quantitative synthesis on the ecosystem services of cover crops. *Earth-Science Reviews*, *185*, 357–373. https://doi.org/10.1016/j.earscirev.2018.06.013

De Notaris, C., Olesen, J., Sørensen, P., & Rasmussen, J. (2020). Input and mineralization of carbon and nitrogen in soil from legume-based cover crops. *Nutrient Cycling in Agroecosystems*, *116*(1), 1–18. https://doi.org/10.1007/s10705-019-10026-z

Furey, G. N., Smukler, S. M., & Riseman, A. (2021). Substituting vetch and chicory for rye in a cover crop mixture enhanced nutrient release. *Canadian Journal of Soil Science*, *101*(2), 339–343. https://doi.org/10.1139/cjss-2020-0106

Hart, J. (2020). High residue cover crops can create 'green bridge' for insect crop pests. *Delta Farm Press*, *77*, 12.

Hossain, S., Bergkvist, G., Berglund, K., Mårtensson, A., & Persson, P. (2012). Aphanomyces pea root rot disease and control with special reference to impact of Brassicaceae cover crops. *Acta Agriculturae Scandinavica, Section B-Soil & Plant Science*, *62*, 477–487. https://doi.org/10.1080/09064710.2012.668218

Kim, N., Zabaloy, M. C., Guan, K., & Villamil, M. B. (2020). Do cover crops benefit soil microbiome? A meta-analysis of current research. *Soil Biology & Biochemistry*, *142*. https://doi.org/10.1016/j.soilbio.2019.107701

Koudahe, K., Allen, S. C., & Djaman, K. (2022). Critical review of the impact of cover crops on soil properties. *International Soil and Water Conservation Research*, *10*(3), 343–354. https://doi.org/10.1016/j.iswcr.2022.03.003

Lamichhane, J. R., & Alletto, L. (2022). Ecosystem services of cover crops: A research roadmap. *Trends in Plant Science*, *27*(8), 758–768. https://doi.org/10.1016/j.tplants.2022.03.014

Lemessa, F., & Wakjira, M. (2015). Cover crops as a means of ecological weed management in agroecosystems. *Journal of Crop Science and Biotechnology*, *18*(2), 123–135. https://doi.org/10.1007/s12892-014-0085-2

Munkholm, L. J., & Hansen, E. M. (2012). Catch crop biomass production, nitrogen uptake and root development under different tillage systems. *Soil Use and Management*, *28*(4), 517–529. https://doi.org/10.1111/sum.12001

Nouri, A., Lukas, S., Singh, S., Singh, S., & Machado, S. (2022). When do cover crops reduce nitrate leaching? A global meta-analysis. *Global Change Biology*, *28*(15), 4736–4749. https://doi.org/10.1111/gcb.16269

Osipitan, O. A., Dille, J. A., Assefa, Y., & Knezevic, S. Z. (2018). Cover crop for early season weed suppression in crops: Systematic review and meta-analysis. *Agronomy Journal*, *110*, 2211. https://doi.org/10.2134/agronj2017.12.0752

Pecetti, L., Carroni, A. M., & Annicchiarico, P. (2020). Performance and adaptability of subterranean clover pure lines and line mixtures of different complexity across contrasting Mediterranean environments. *Field Crops Research*, *256*, 107907. https://doi.org/10.1016/j.fcr.2020.107907

Peltonen-Sainio, P., & Jauhiainen, L. (2019). Unexploited potential to diversify monotonous crop sequencing at high latitudes. *Agricultural Systems*, *174*, 73–82. https://doi.org/10.1016/j.agsy.2019.04.011

Peltonen-Sainio, P., & Jauhiainen, L. (2020). Large zonal and temporal shifts in crops and cultivars coincide with warmer growing seasons in Finland. *Regional Environmental Change*, *20*(3), 89. https://doi.org/10.1007/s10113-020-01682-x

Peltonen-Sainio, P., Jauhiainen, L., & Känkänen, H. (2023). Finnish farmers feel they have succeeded in adopting cover crops but need down-to-earth support from research. *Agronomy*, *13*(9), 2326. https://doi.org/10.3390/agronomy13092326

Peltonen-Sainio, P., Jauhiainen, L., Känkänen, H., Joona, J., Hydén, T., & Mattila, T. J. (2022). Farmers' experiences of how under-sown clovers, ryegrasses, and timothy perform in northern European crop production systems. *Agronomy*, *12*(6), 1401. https://doi.org/10.3390/agronomy12061401

Peltonen-Sainio, P., Jauhiainen, L., Mattila, T., Joona, J., Hydén, T., & Känkänen, H. (2022). Pioneering farmers value agronomic performance of cover crops and their impacts on soil and environment. *Sustainability*, *14*(13), 8067. https://doi.org/10.3390/su14138067

Peltonen-Sainio, P., Jauhiainen, L., Palosuo, T., Hakala, K., & Ruosteenoja, K. (2016). Rainfed crop production challenges under European high latitude conditions. *Regional Environmental Change*, *16*(5), 1521–1533. https://doi.org/10.1007/s10113-015-0875-1

Poeplau, C., & Don, A. (2015). Carbon sequestration in agricultural soils via cultivation of cover crops – A meta-analysis. *Agriculture, Ecosystems & Environment*, *200*, 33–41. https://doi.org/10.1016/j.agee.2014.10.024

Rouge, A., Adeux, G., Busset, H., Hugard, R., Martin, J., Matejicek, A., Moreau, D., Guillemin, J.-P., & Cordeau, S. (2023). Carry-over effects of cover crops on weeds and crop productivity in no-till systems. *Field Crops Research*, *295*, 108899. https://doi.org/10.1016/j.fcr.2023.108899

Ruis, S. J., & Blanco-Canqui, H. (2017). Cover crops could offset crop residue removal effects on soil carbon and other properties: A review. *Agronomy Journal*, *109*(5), 1785–1805. https://doi.org/10.2134/agronj2016.12.0735

Ruosteenoja, K., Jylhä, K., & Kämäräinen, M. (2016). Climate projections for Finland under the RCP forcing scenarios. *Geophysica*, *51*, 17–50.

Scavo, A., Fontanazza, S., Restuccia, A., Pesce, G. R., Abbate, C., & Mauromicale, G. (2022). The role of cover crops in improving soil fertility and plant nutritional status in temperate climates. A review. *Agronomy for Sustainable Development*, *42*(5), 93. https://doi.org/10.1007/s13593-022-00825-0

Sieling, K. (2019). Improved N transfer by growing catch crops – a challenge. *Journal of Cultivated Plants*, *71*, 145–160. https://doi.org/10.5073/JfK.2019.06.01

Stoa, T. E. (1933). Persistence of viability of sweet clover seed in a cultivated soil. *Agronomy Journal*, *25*(3), 177–181. https://doi.org/10.2134/agronj1933.00021962002500030002x

Stoate, C., Báldi, A., Beja, P., Boatman, N. D., Herzon, I., van Doorn, A., de Snoo, G. R., Rakosy, L., & Ramwell, C. (2009). Ecological impacts of early 21st century agricultural change in Europe – A review. *Journal of Environmental Management*, *91*(1), 22–46. https://doi.org/10.1016/j.jenvman.2009.07.005

Stokes, M. E., Davis, C. S., & Koch, G. G. (2001). *Categorical data analysis using The SAS system* (2nd Edition). Wiley-SAS. 648 p.

Teixeira, C., Hampton, J., & Moot, D. (2021). Phenological development of subterranean clover cultivars under contrasting environments. *Annals of Applied Biology*, *179*(2), 246–258. https://doi.org/10.1111/aab.12693

Thorup-Kristensen, K., & Rasmussen, C. R. (2015). Identifying new deep-rooted plant species suitable as undersown nitrogen catch crops. *Journal of Soil and Water Conservation*, *70*(6), 399–409. https://doi.org/10.2489/jswc.70.6.399

Tuulos, A., Yli-Halla, M., Stoddard, F., & Mäkelä, P. (2015). Winter turnip rape as a soil N scavenging catch crop in a cool humid climate. *Agronomy for Sustainable Development*, *35*(1), 359–366. https://doi.org/10.1007/s13593-014-0229-2

Valkama, E., Lemola, R., Känkänen, H., & Turtola, E. (2015). Meta-analysis of the effects of undersown catch crops on nitrogen leaching loss and grain yields in the Nordic countries. *Agriculture, Ecosystems & Environment*, *203*, 93–101. https://doi.org/10.1016/j.agee.2015.01.023

Vincent-Caboud, L., Peigné, J., Casagrande, M., & Silva, E. M. (2017). Overview of organic cover crop-based no-tillage technique in Europe: Farmer's practices and research challenges. *Agriculture*, *7*(5), 42. https://doi.org/10.3390/agriculture7050042

Vogeler, I., Hansen, E. M., Thomsen, I. K., & Østergaard, H. S. (2019). Legumes in catch crop mixtures: Effects on nitrogen retention and availability, and leaching losses. *Journal of Environmental Management*, *239*, 324–332. https://doi.org/10.1016/j.jenvman.2019.03.077

Wittwer, R. A., & van der Heijden, M. G. A. (2020). Cover crops as a tool to reduce reliance on intensive tillage and nitrogen fertilization in conventional arable cropping systems. *Field Crops Research*, *249*, 107736. https://doi.org/10.1016/j.fcr.2020.107736

Zhao, J., Bindi, M., Eitzinger, J., Ferrise, R., Gaile, Z., Gobin, A., Holzkämper, A., Kersebaum, C., Kozyra, J., Loit, E., Nejedlik, P., Nendel, C., Niinemets, Ü, Palosuo, T., Peltonen-Sainio, P., Potopova, V., Ruiz Ramos, M., Reidsma, P., Rijk, B., … Olesen, J. E. (2022). Priority for climate adaptation measures in European crop production systems. *European Journal of Agronomy*, *138*, 126516. doi:10.1016/j.eja.2022.126516